N-ZERO
Near Zero Power RF and Sensor Operations

Proposers' Day

Dr. Troy Olsson

1/29/2015

Agenda

- 8:00AM - 8:30AM Registration & Poster Set Up
- 8:30AM - 8:40AM Welcome & Ground Rules
- 8:40AM - 9:30AM Program Overview & Structure
- 9:30AM - 10:00AM N-ZERO Q & A
- 10:00AM - 10:15AM Break
- 10:15AM - 11:00AM MIT-LL Presentation
- 11:00AM - 11:30AM Testing & Data Q & A
- 11:30AM - 12:30PM Lunch / Private Poster Session
- 12:30PM - 1:00PM Break
- 1:00PM - 5:00PM Open Poster Session & Teaming
- 1:00PM - 5:00PM One-on-One Meetings with the PM

Ground Rules

Until the deadline for receipt of proposals:

- Open communications between proposers and the program manager are encouraged.
  - However, any **information** given to one proposer must be **available to all proposers**.
- The best way to have a question answered is to submit it via email.
  - Responses will be posted at the Questions and Answers list on the MTO solicitations website.
  - Any question that contains distribution restrictions, such as 'company proprietary', will **not be answered**.

Please submit questions to

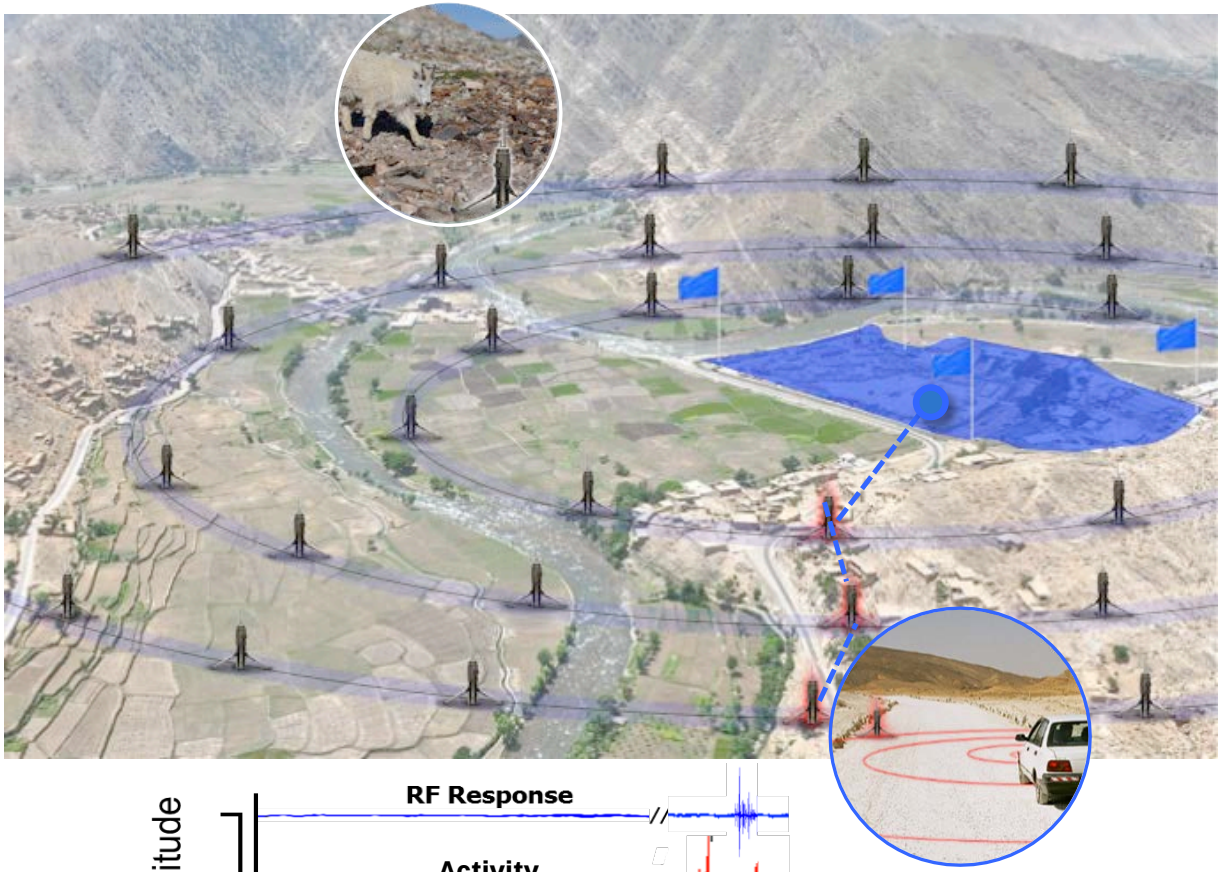
DARPA-BAA-15-14@darpa.mil

Purpose of this meeting:

- Discuss program objectives and structure.
- Provide opportunity for teaming prior to proposal deadline.

Program Overview

N-ZERO Vision: Persistent Sensing for the DoD

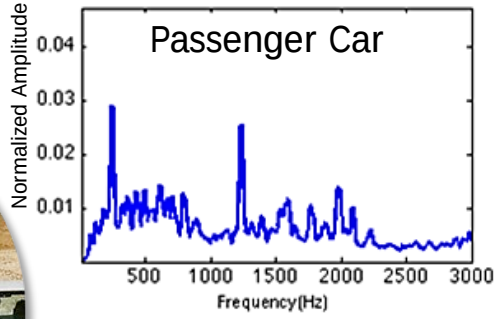


Geophone recording of activity followed by RF transmission

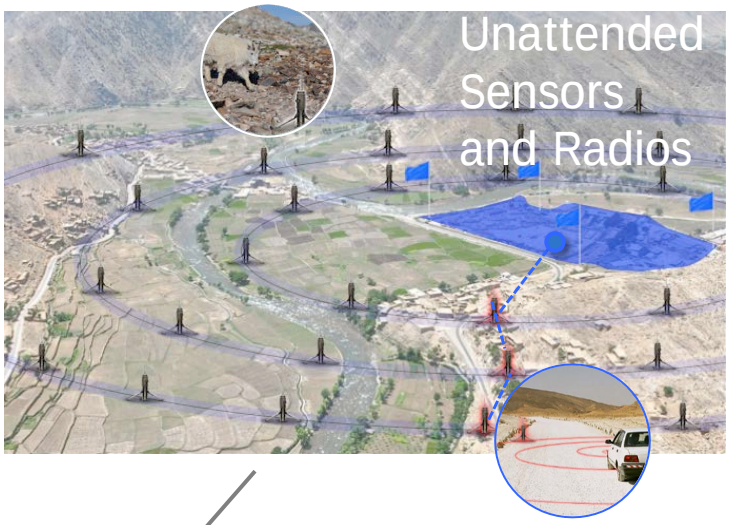
N-ZERO seeks to greatly extends mission capabilities and lifetime at reduced cost

Current SOA:
Awaiting Activity Constrains Mission Life

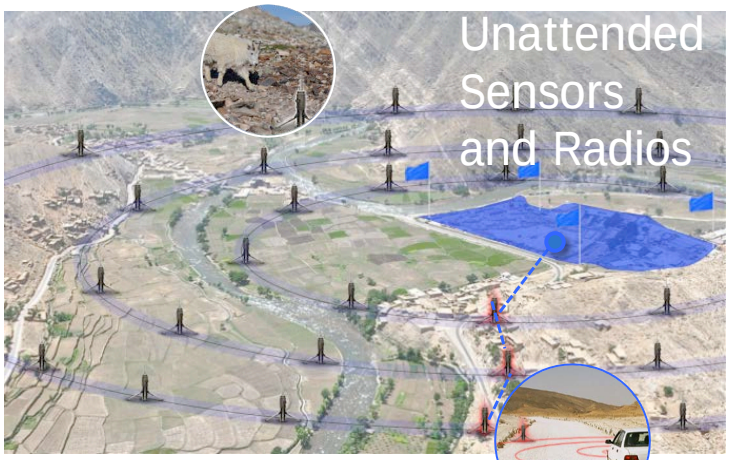
Acoustic Signature
@ 3 m Standoff



Current SOA:
Awaiting Activity Constrains Mission Life



Current SOA:
Awaiting Activity Constrains Mission Life



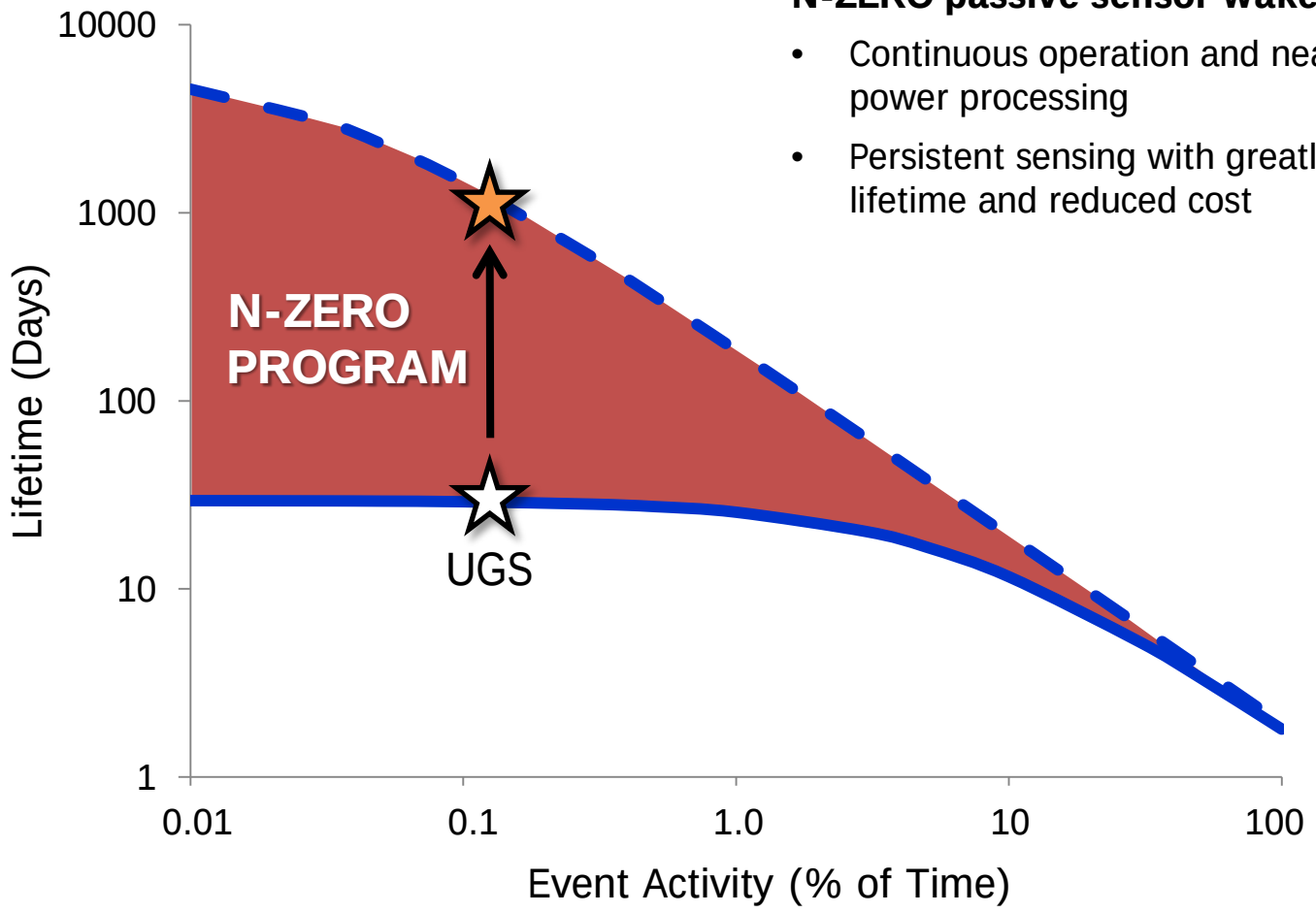
Coin Cell Lifetime (Days)

10000
1000
100
10
1

Staying ALERT requires ACTIVE POWER!

Sensor	0.14	1.4	14	144	1440	Recording (Min./Day)
Radio	0.1	1	10	100	1000	Comms. (Mb/Day)

N-ZERO Vision: OFF but ALERT!



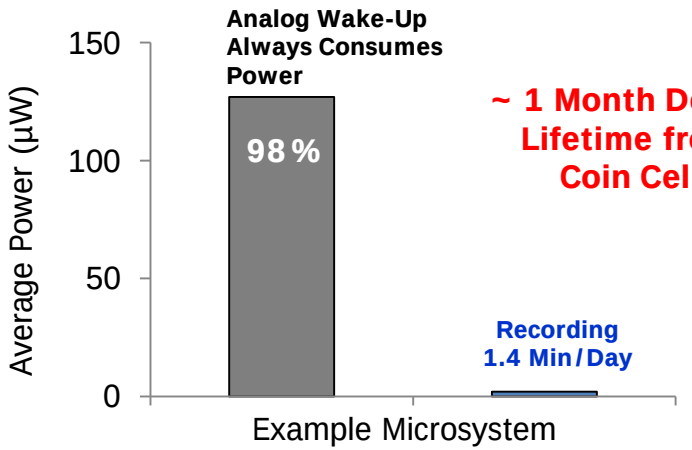
N-ZERO passive sensor wake-up:

- Continuous operation and near-zero power processing
- Persistent sensing with greatly extended lifetime and reduced cost

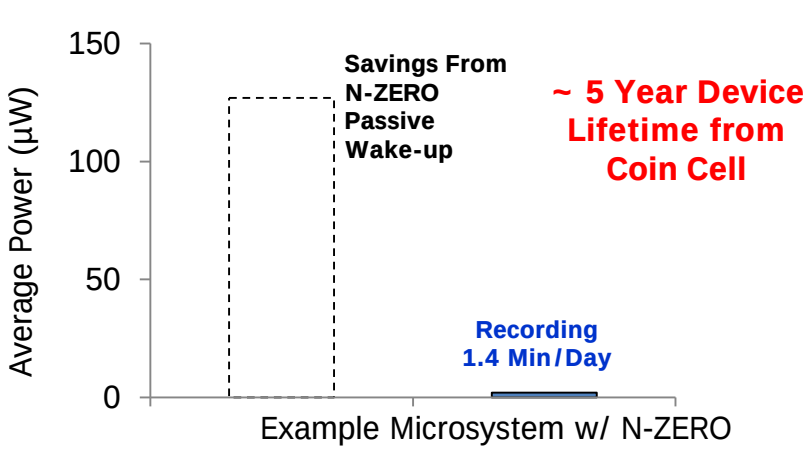
N-ZERO: Devices are OFF (Zero Power Consumption) Yet Continually ALERT!

The N-ZERO Advantage

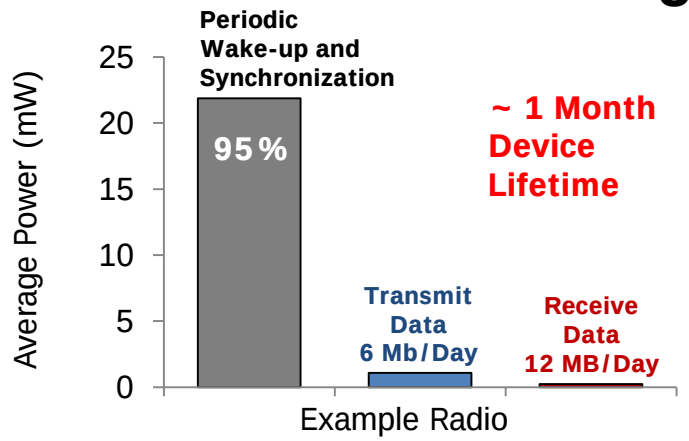
Unattended Ground Sensors



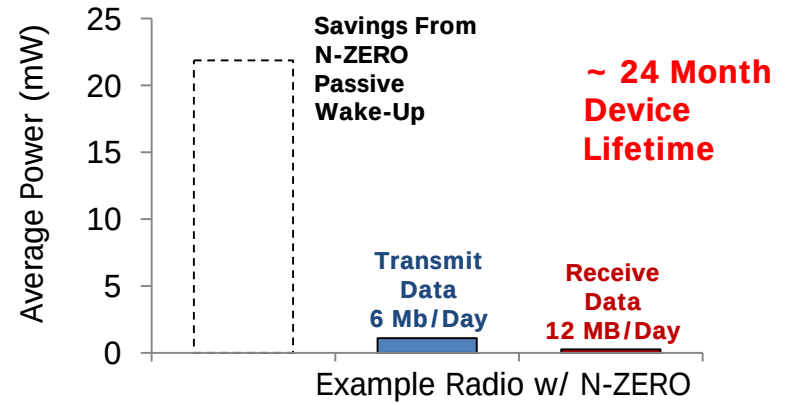
N-ZERO



UGS RF Transceivers



N-ZERO

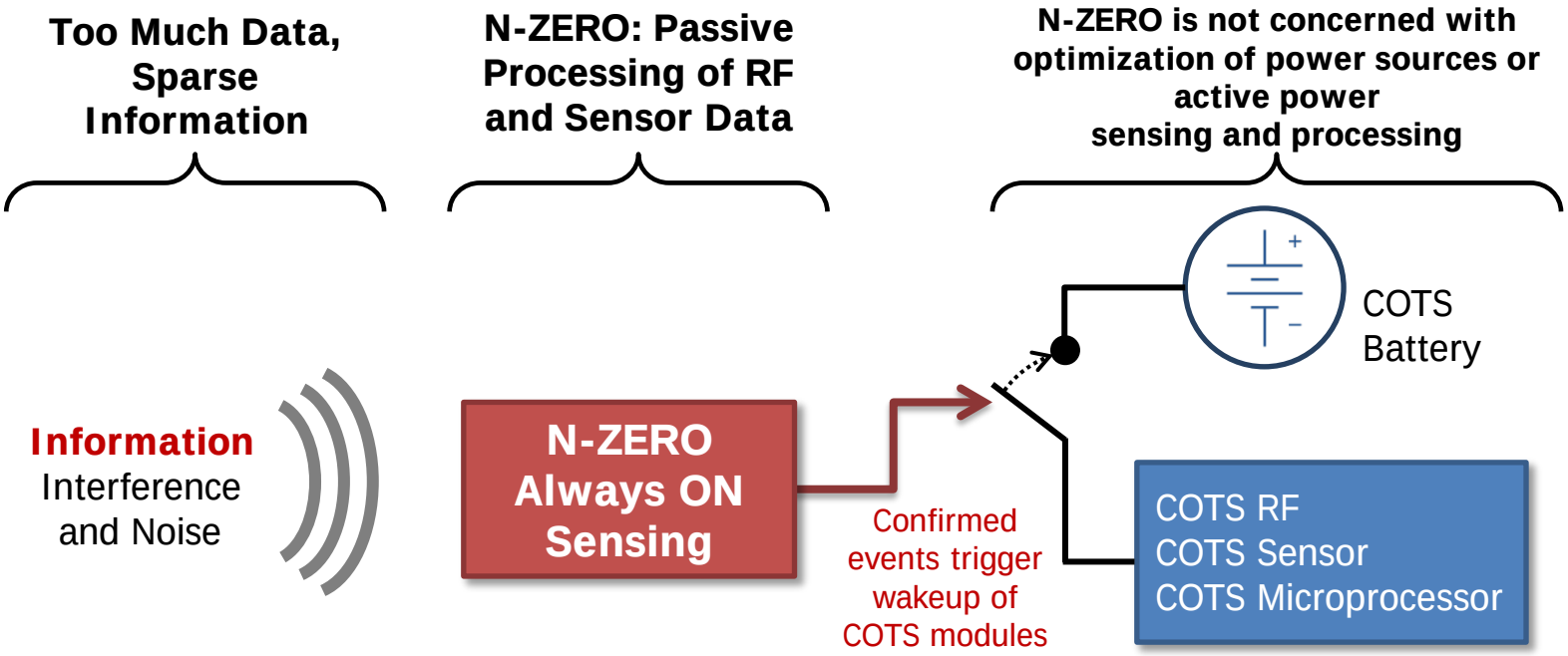


- Staying Alert Requires Active Power
- Wake-Up and Synchronization Consume **> 95 %** of Battery Life for Sparse Signals

- OFF but Constantly ALERT
- Wake-Up and Synchronization Do Not Drain Lifetime

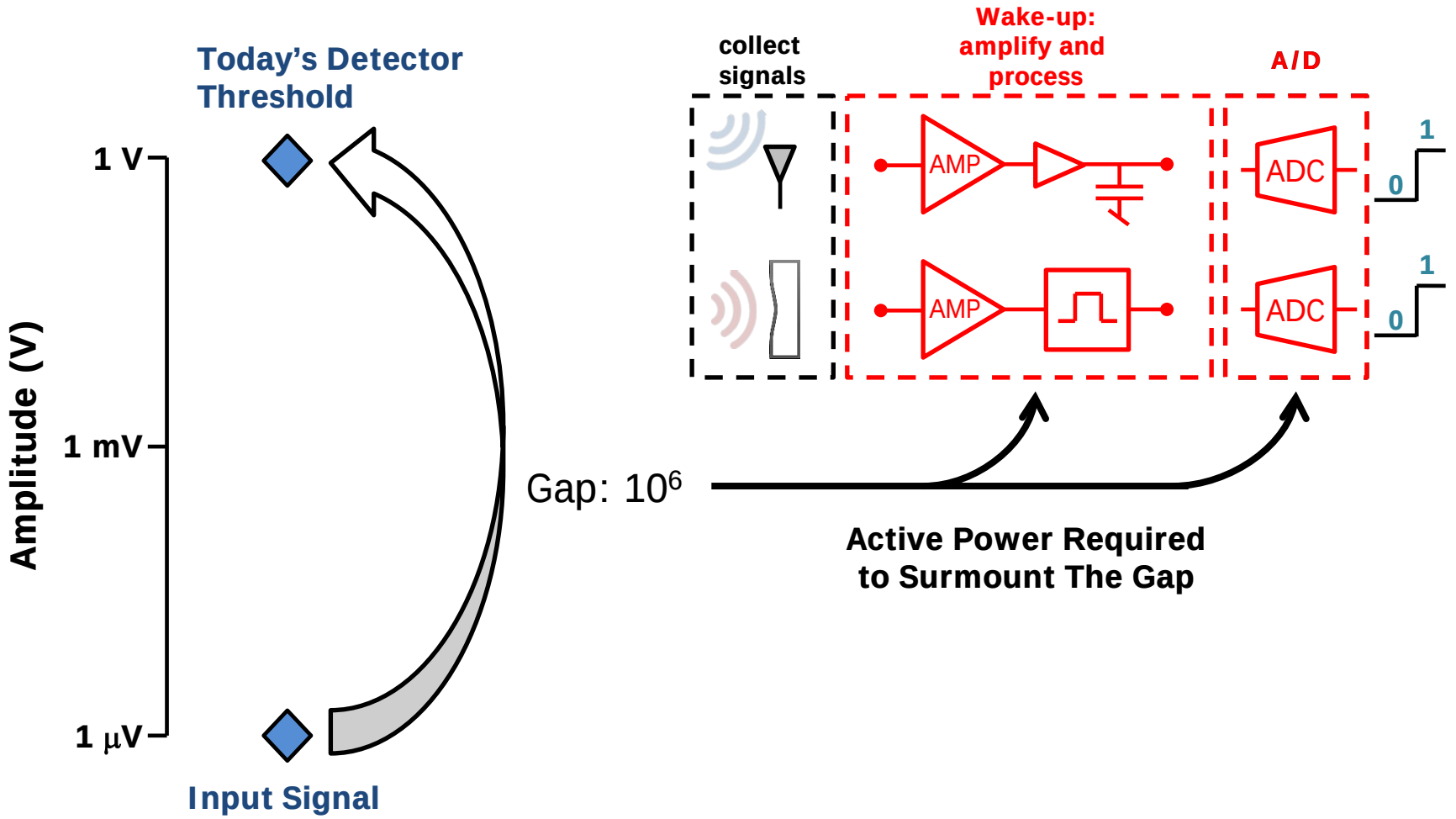
N-ZERO Concept

- N-ZERO senses the environment 100% of the time at near zero power (<10 nW, which is below the leakage rate for small batteries)
- N-ZERO uses energy in the signals to perform pre-processing to detect information while rejecting noise and interference
- Upon detection of an event, N-ZERO triggers activation of the COTS module for further processing and follow-up action



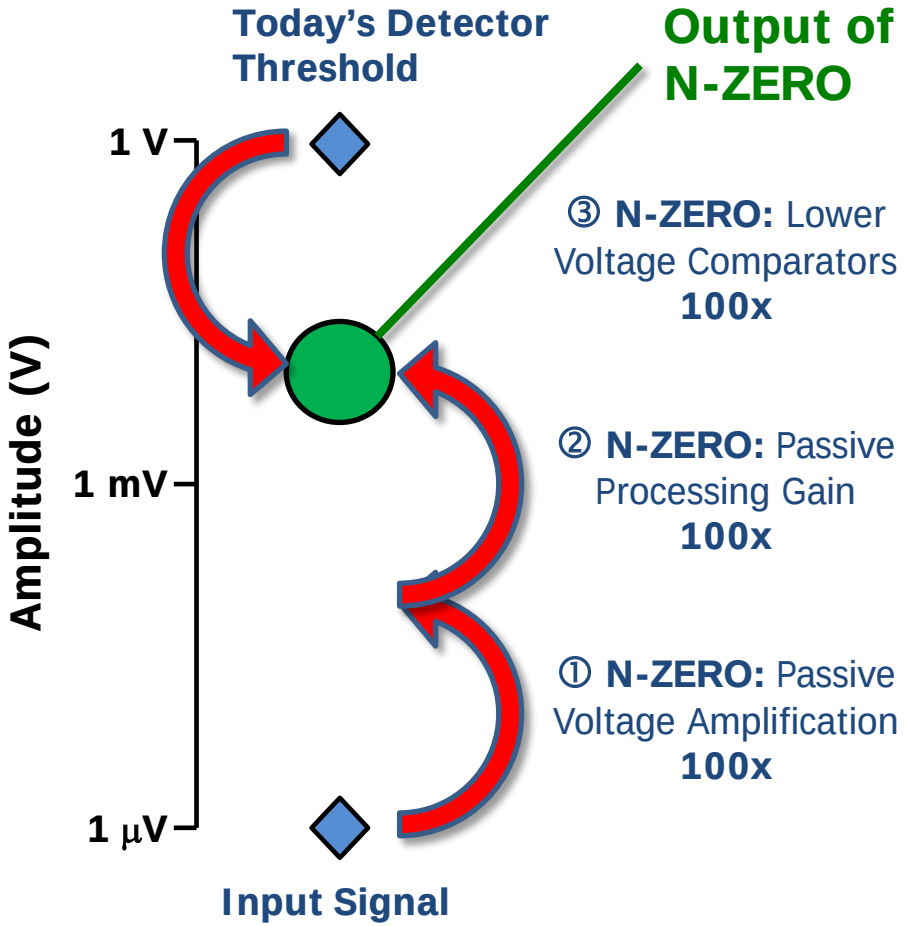
*** N-ZERO does not replace COTS functionality. Instead, it aims to significantly reduce COTS "on" time, thereby dramatically increasing the sensor's useful lifetime.**

The N-ZERO Challenge and SOA

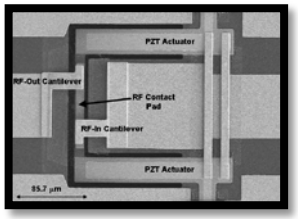


The Gap Between Signal Levels and Detector Threshold Voltages Is Bridged by Active Power Amplification, Signal Processing and A/D Conversion

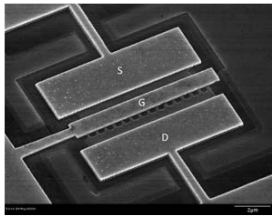
A Notional Approach: Passive Sensing



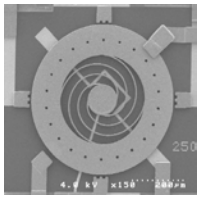
Notional Devices (not limited to these examples)



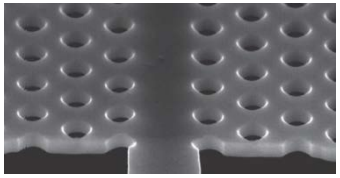
MEMS Switch



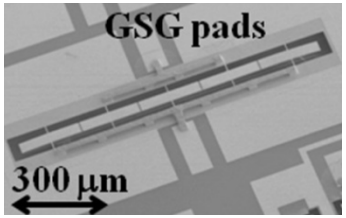
Tunnel Field Effect Transistor



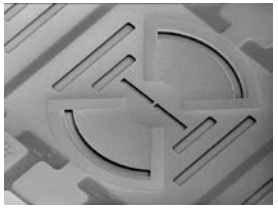
Acceleration Switch



Dispersive Delay Line



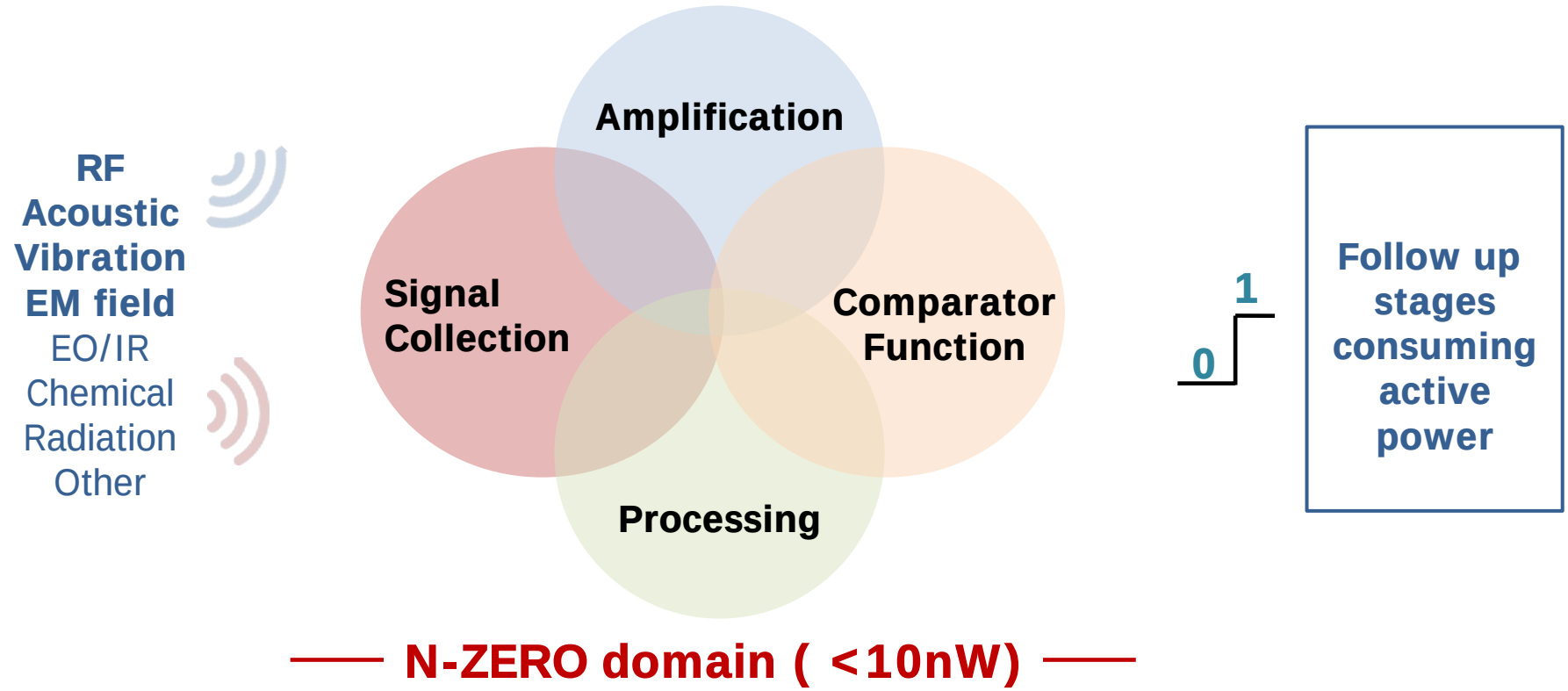
Piezoelectric Transformer



GHz Dispacement Amplfier

N-ZERO Endeavors to Develop the Technological Base to Close the 10^6 Gap for a Zero Power Wake-up Capability

N-ZERO Concept



BAA Overview

Program Objective

- Exploit the energy within a signature to detect and discriminate events of interest while rejecting noise and interference
- N-ZERO signal sensing must be continuous
- Power budget of ≤ 10 nW
- **Non-responsive** approaches include (but are not limited to)
  - energy harvesting other than from the signature
  - optimized or alternate power sources
  - systems that do not result in continuous sensing

Total anticipated budget:

- $25M for Technical Area 1 (Microsystems)
- $5M for Technical Area 2 (Devices)

Expected duration

- 39 months for TA-1
- 27 to 33 months for TA-2

Anticipated individual awards multiple

Anticipated funding type 6.1 and/or 6.2

Technical Areas of Interest

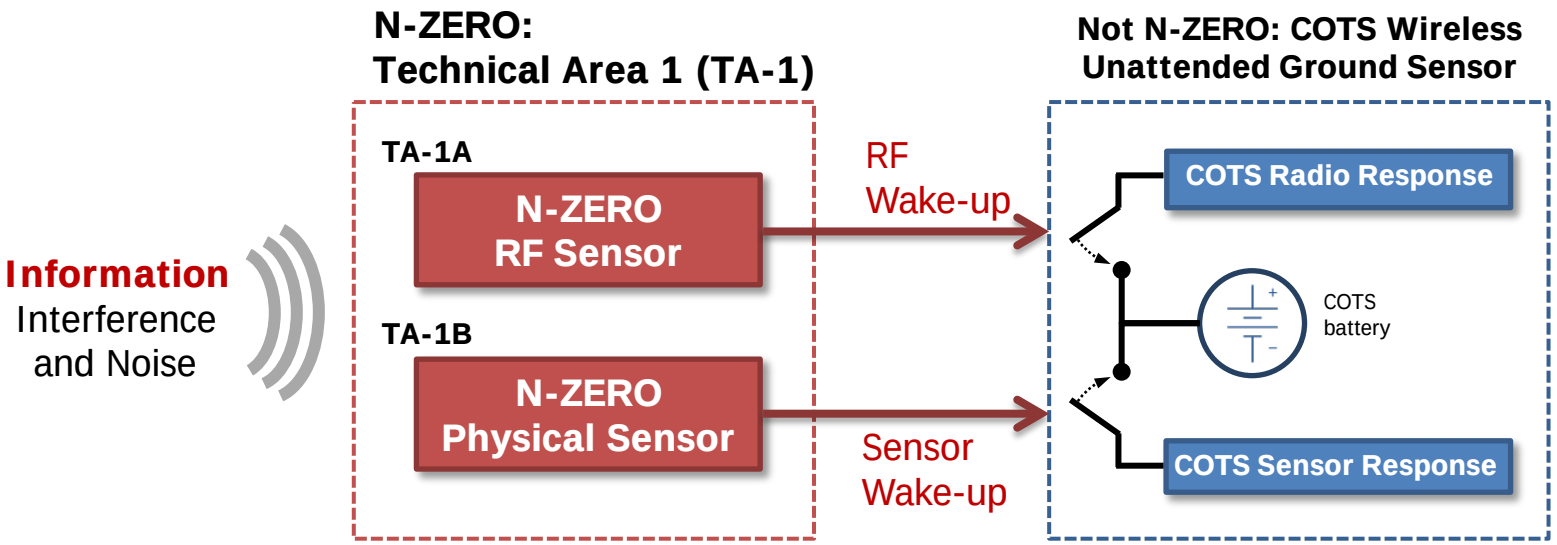
- Technical Area 1 – Microsystems
  - (1A) RF Microsystems
  - (1B) Physical Sensor Microsystems

  - Can be combined in one proposal
  - Commonality between components encouraged
  - ≤10 nW for each

- Technical Area 2 – Devices
  - (2A) Digitizing Sensor Microsystems
  - (2B) RF Voltage Amplifiers
  - (2C) Low-Threshold Comparators

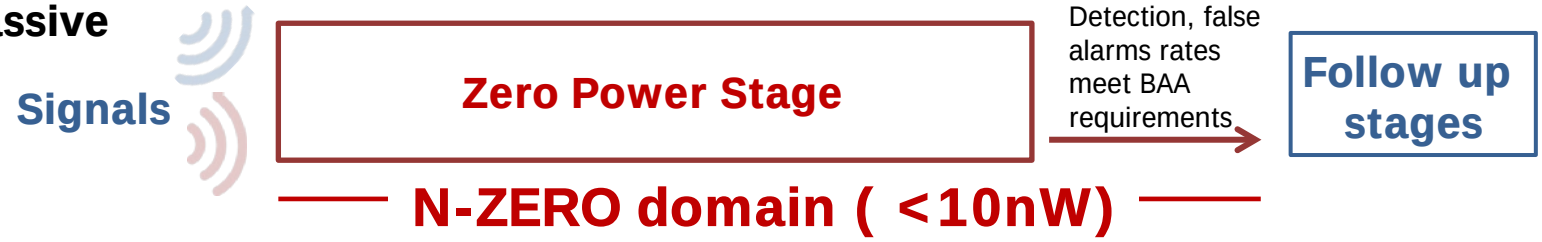
TA-1 - Microsystems

- Full microsystem to detect signatures and produce a digital output bit
- Proposer defined metrics must be justified in the abstract and proposal
- Tested by
  - Proposer
  - Government laboratory

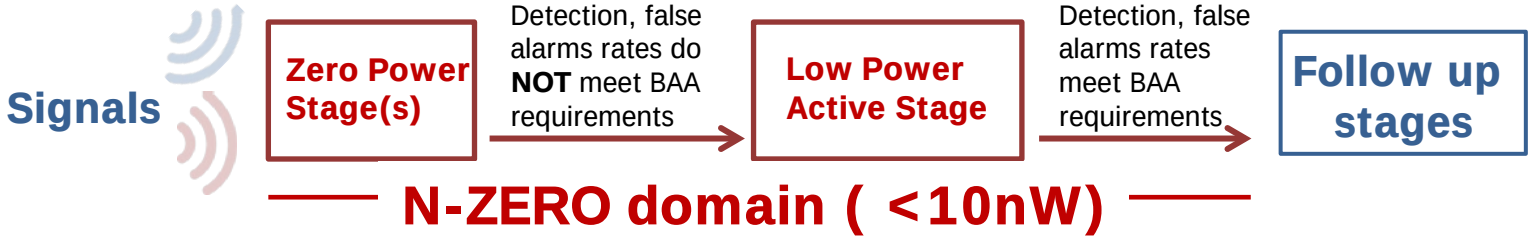


Example N-ZERO Architectures

Fully Passive



Combined Passive and Active

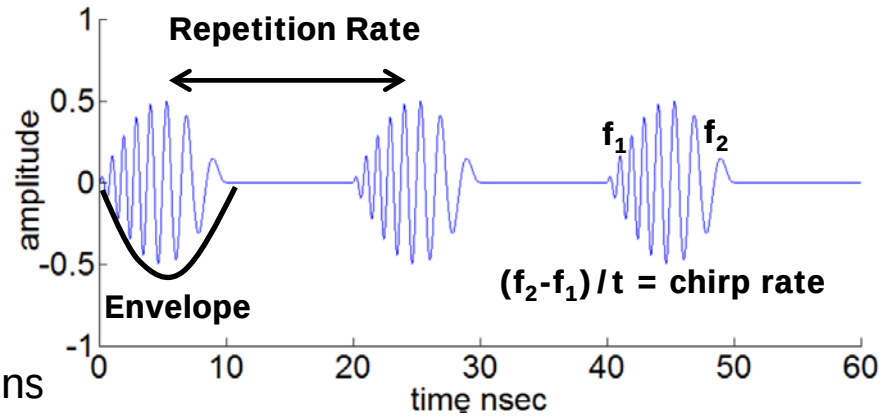


Most important performance metrics:

- Lowest power ≤ 10 nW
- Highest probability of detection ≥ 95%
- Lowest false alarm rate ≤ 1/hour
- Minimum detectable signal as low as possible

TA-1A RF Microsystems

- Detect RF signature
- Proposers define RF signatures within 50 MHz to 1 GHz
- Signature specification (by performer) to include:
  - RF carrier frequency
  - Additional tones, chirp rates and durations
  - Pulse repetition rates
  - Modulation types
  - and/or other waveform characteristics



- Signature design to optimize system performance is required
- The system will be able to discriminate the signature of interest in the presence of interfering signals and a noisy RF background
- A proposer-provided 50 Ω SMA or other commonly available RF connection will serve as the sensor's physical input port
- Antenna design is not a part of the N-ZERO program and therefore should not be considered as a means to boost sensor input gain
- Proposals for the development of transmitters to emit this signature waveform are **non-responsive to this BAA**

TA-1A RF Microsystem Metrics

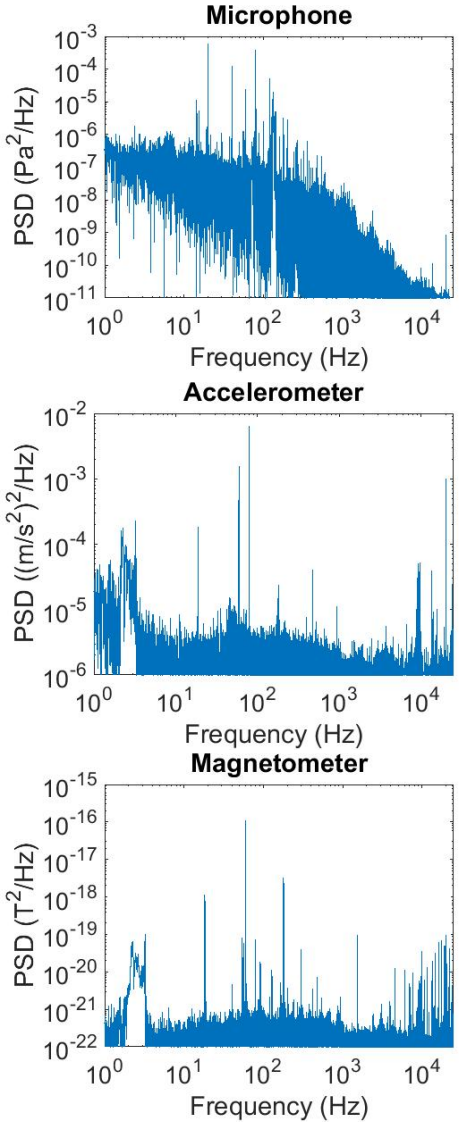
Metric	Phase I	Phase II	Phase III
RF Signature Type	RF Tone	RF Chirp	Proposer Defined
RF Level At Sensor Input	≤ -60 dBm	≤ -80 dBm	≤ -100 dBm
RF Frequency Limits	0.05-1 GHz	0.05-1 GHz	0.05-1 GHz
Digital Output Voltage Indicating Positive Detection	≥ 1 V	≥ 1 V	≥ 1 V
Received Energy Required for Signature Detection	≤ 30 pJ	≤ 300 fJ	≤ 3 fJ
Environment*	low interference background	high interference background	high interference background

* Proposers must send an email to DARPA-BAA-15-14@darpa.mil with the subject "**RF DATA**" and/or "**SENSOR DATA**" to obtain Government-provided data.

TA-1B Physical Sensor Microsystems

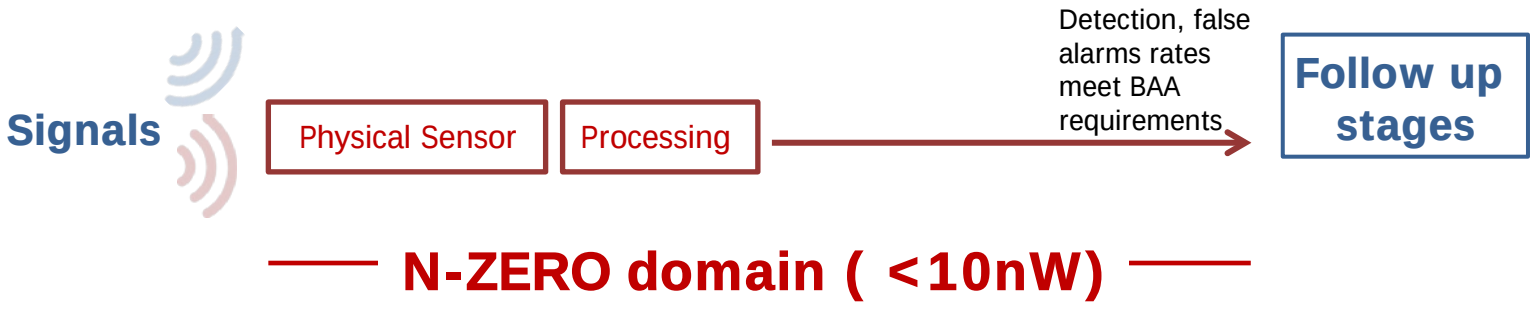
- Detect physical signatures
- Background will contain noise and interferers
- Target electro-mechanical machinery
  - electrical generator
  - passenger car
  - truck
- Select signature features to optimize
  - power
  - probability of detection
  - false alarm rate
  - minimum detectable level
- Government-provided data
  - acoustic
  - vibration
  - ground displacement
  - magnetic field
- Types of sensors must outlined in the abstract and proposal

Measurements are 5m from the generator.

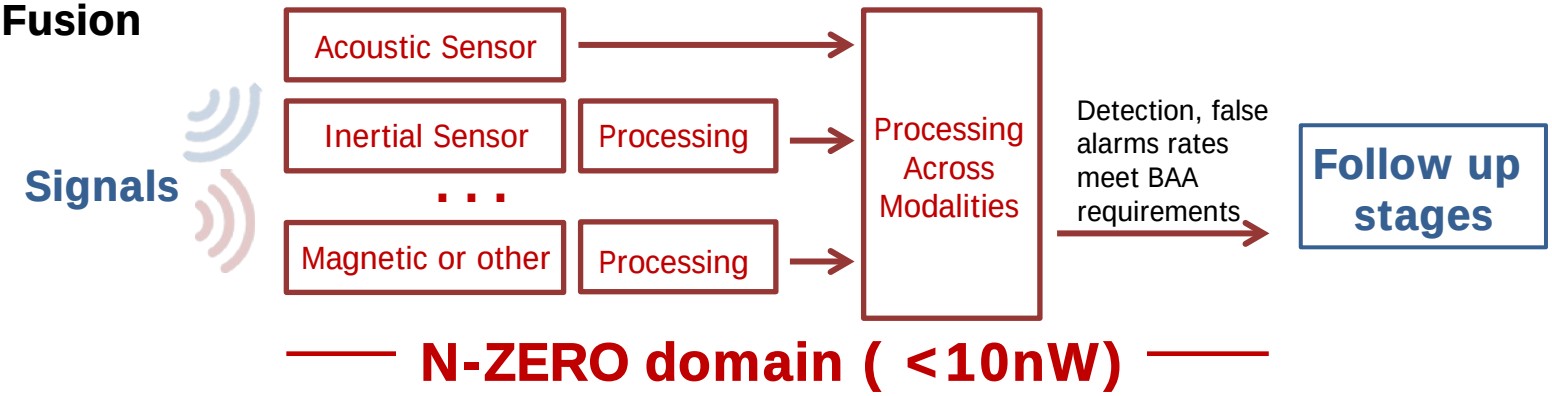


Example N-ZERO Architectures

Single-Modality Sensing



Sensor Fusion



Most important performance metrics:

- Lowest power ≤ 10 nW
- Highest probability of detection ≥ 95%
- Lowest false alarm rate ≤ 1/hour
- Minimum detectable signal as low as possible

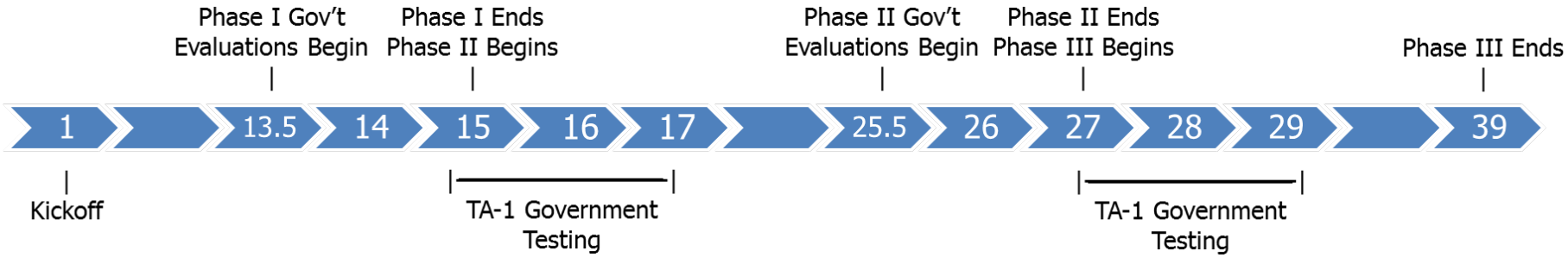
TA-1B Physical Sensor Microsystem Metrics

Metric	Phase I	Phase II	Phase III
Devices to be Detected	Generator	Generator, Car, Truck	Generator, Car, Truck
Signatures to be Utilized for Detection	Performer Defined	Performer Defined	Performer Defined
Distance to Physical Source	< 0.5 m	< 0.5 m	≥ 10 m
Digital Output Voltage Indicating Positive Detection	≥ 1 V	≥ 1 V	≥ 1 V
Environment*	rural	urban	urban

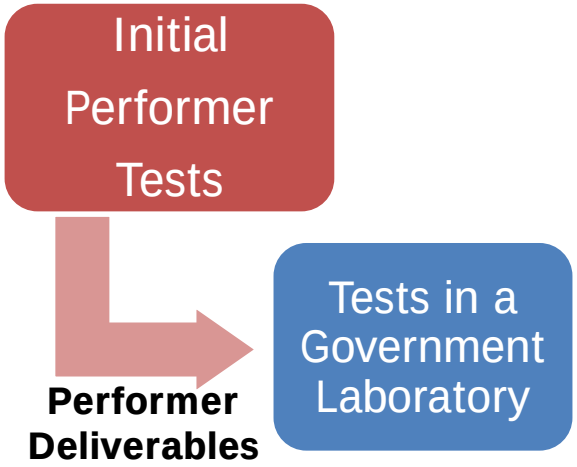
* Proposers must send an email to DARPA-BAA-15-14@darpa.mil with the subject "**RF DATA**" and/or "**SENSOR DATA**" to obtain Government-provided data.

TA-1 Testing Plan Overview

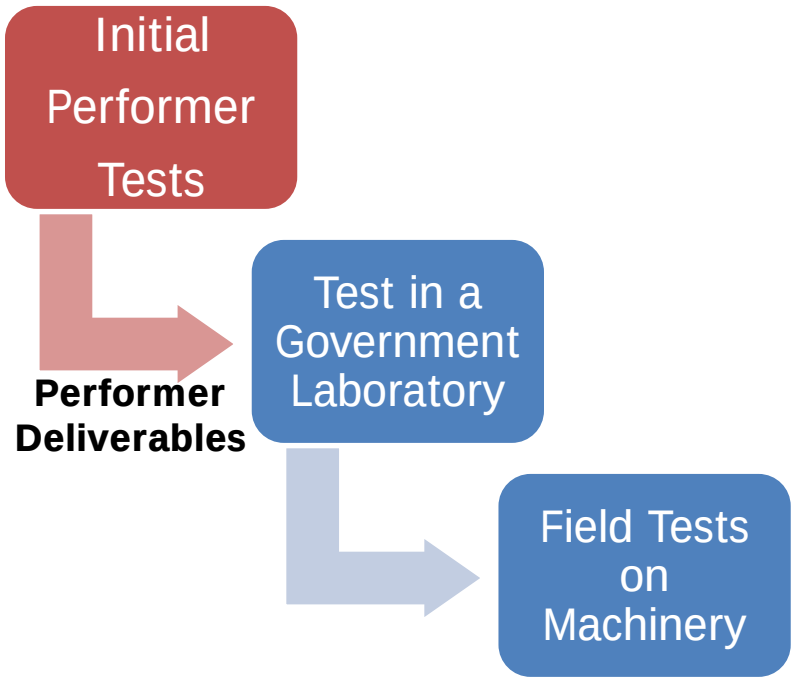
Timeline



TA-1A



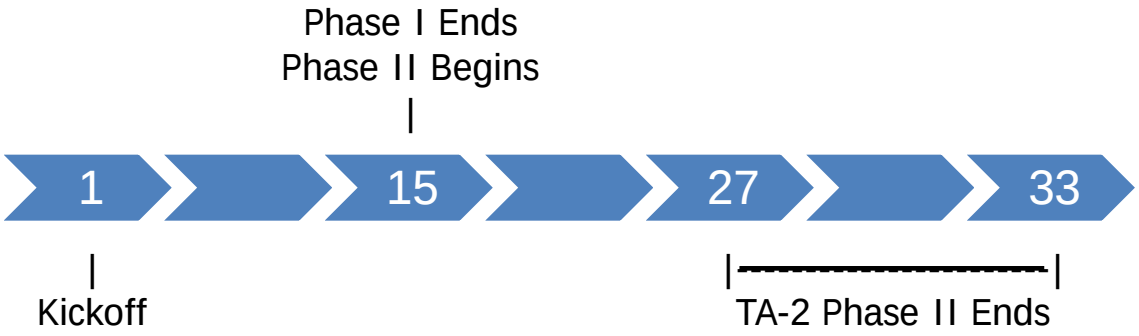
TA-1B



TA-2 - Devices

- Microsystems that sense modalities not present in TA-1
- Components that are part of the full N-ZERO microsystem
- Concentrate on high-risk, high-reward components
- Proposer defined metrics must be justified in the abstract and proposal
- Abstract and proposal must contain details on
  - testing plan
  - signature definition and generation
  - selectivity and definition of the selectivity measurement
- Tested by the proposer

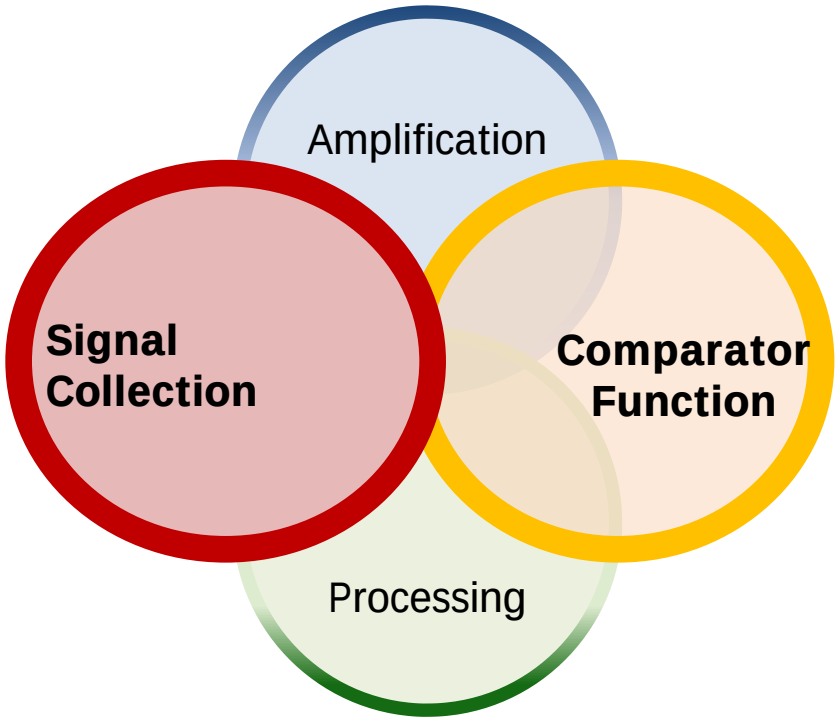
Timeline



TA-2A Digitizing Sensor Microsystems

- Produce a quantized output bit in the presence of a sensor signature
- One- or few-shot sensors are **non-responsive to this BAA**
- Sensors covering a single sensing modality
- Modalities not covered in TA-1 that are of particular interest:
  - infrared
  - radiation
  - chemical
  - etc.

RF
Acoustic
Vibration
EM field
EO / IR
Chemical
Radiation
Other



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Follow up stages consuming active power

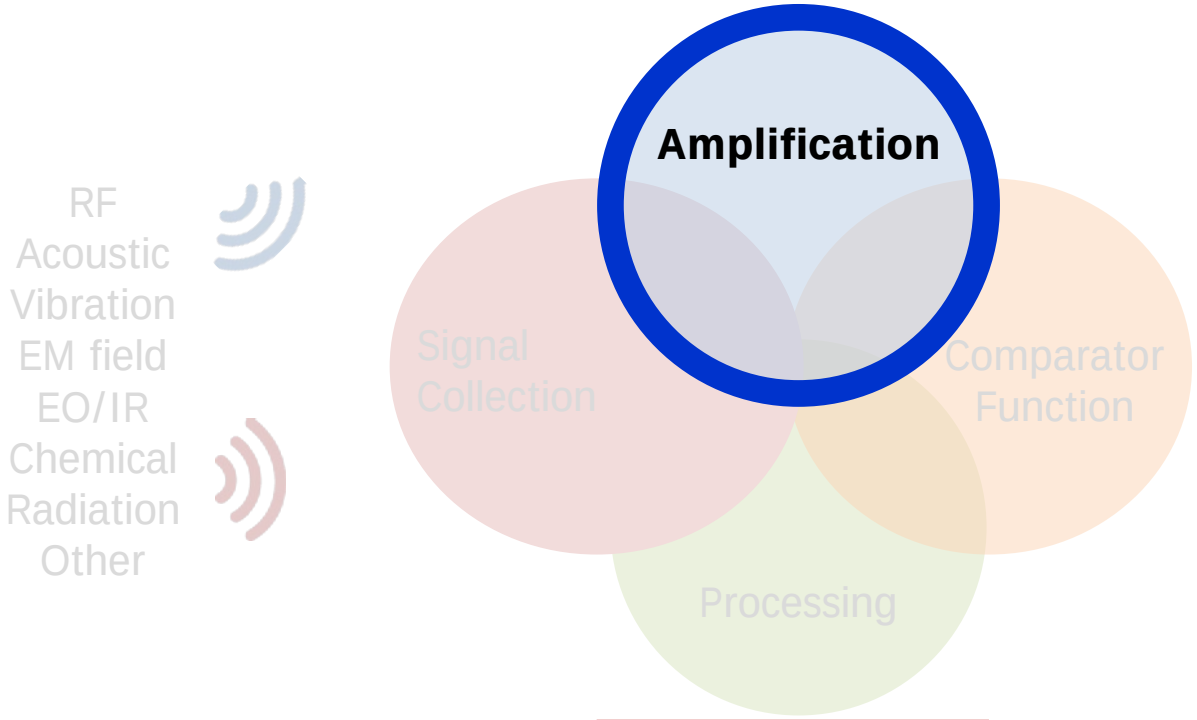
N-ZERO domain (<10nW)

TA-2A Digitizing Sensor Microsystem Metrics

Metric	Phase I	Phase II
Sensor Type (e.g. light, thermal, etc.)	Performer Defined	Performer Defined
Threshold Level (e.g. in units of lm, °C, etc.)	Performer Defined Phase I Goal	< 5 Times Phase I Goal
Digital Output Voltage Indicating Positive Detection	≥ 1 V	≥ 1 V
Sub-Threshold Swing (e.g. in units of lm/decade, °C/decade, etc.)	Performer Defined Phase I Goal	< 5 Times Phase I Goal
Threshold Signature	Performer Defined	Performer Defined
Number of Detection Cycles	> 10	> 1000
Power Consumption When Signature is Absent	≤ 10 nW	≤ 10 nW

TA-2B RF Voltage Amplifiers

- High-performance voltage gain
- Materials that significantly advance the state-of-the-art are of particular interest
- Center frequency from 0.05 to 1 GHz (proposer-selected)

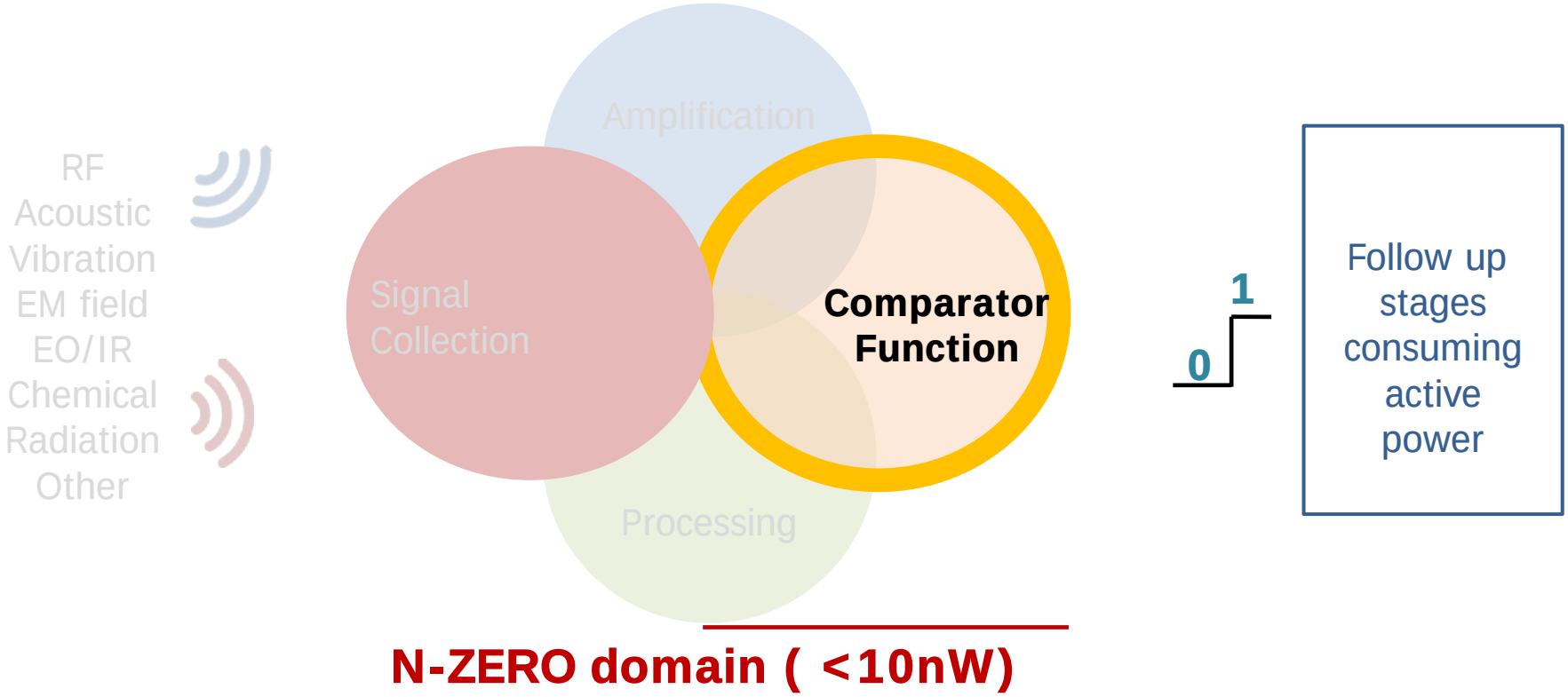


TA-2B RF Amplifier Metrics

Metric	Phase I	Phase II
RF Center Frequency Limits	0.05 to 1 GHz	0.05 to 1 GHz
Bandwidth	Proposer Defined	Proposer Defined
Input Source Impedance	50 Ω	50 Ω
Output Impedance	Proposer Defined	Proposer Defined
Voltage Gain/Frequency	10 (V/V/GHz)	40 (V/V/GHz)
Power Consumption	≤ 10 nW	≤ 10 nW

TA-2C Low-Threshold Comparators

- Low-threshold voltage results in a relaxation of the requirements on other components in the microsystem



TA-2C Low-Threshold Comparator Metrics

Metric	Phase I	Phase II
Threshold Voltage (V_t)	< 20 mV	< 5 mV
Number of Comparators on a Single Die	3	10
Threshold Voltage Precision	≤ 5 mV	≤ 2 mV
Sub-Threshold Swing from $0 < V_{in} < V_t$	< 4 mV/Dec	< 0.5 mV/Dec
Gate Capacitance	< 10 fF	< 10 fF
Resistance at $V_{in} = V_t$	< 10 kΩ	< 10 kΩ
Number of Cycles	> 10	> 1000
Power Consumption at $V_{in} < 0.1$ mV	≤ 10 nW	≤ 10 nW

Program Structure

Proposal Evaluation Criteria

a) Overall Scientific and Technical Merit

b) Potential Contribution and Relevance to the DARPA Mission

c) Realism of Proposed Cost and Schedule

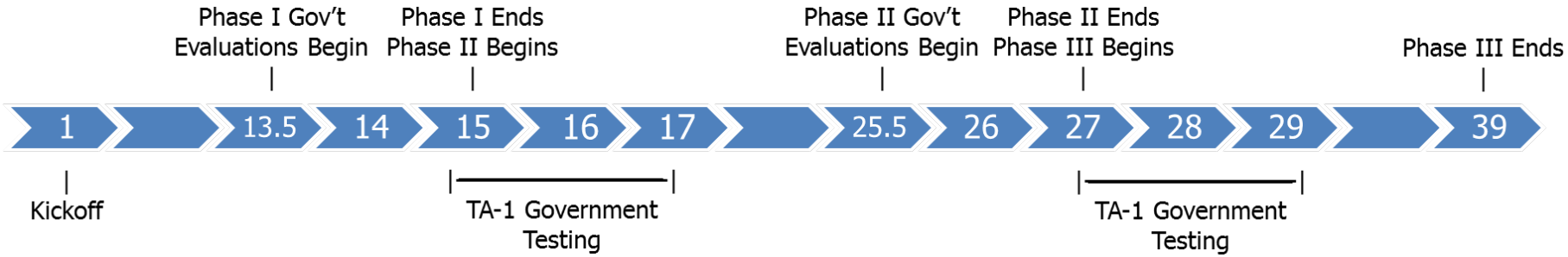
d) Plans and Capability to Accomplish Technology Transition

Deliverables

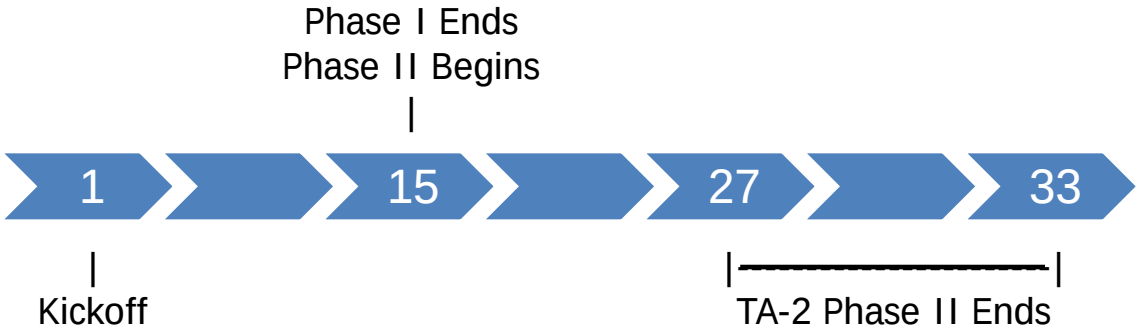
- TA-1
  - Quantity of 3 identical microsystems at the conclusion of each phase
- TA-1A
  - Data file containing a time domain representation of the proposer defined RF waveform at the conclusion of each phase
- TA-1 and TA-2
  - Quarterly technical update reports
  - Final report at the end of each phase

Project Timelines

TA-1 Microsystems



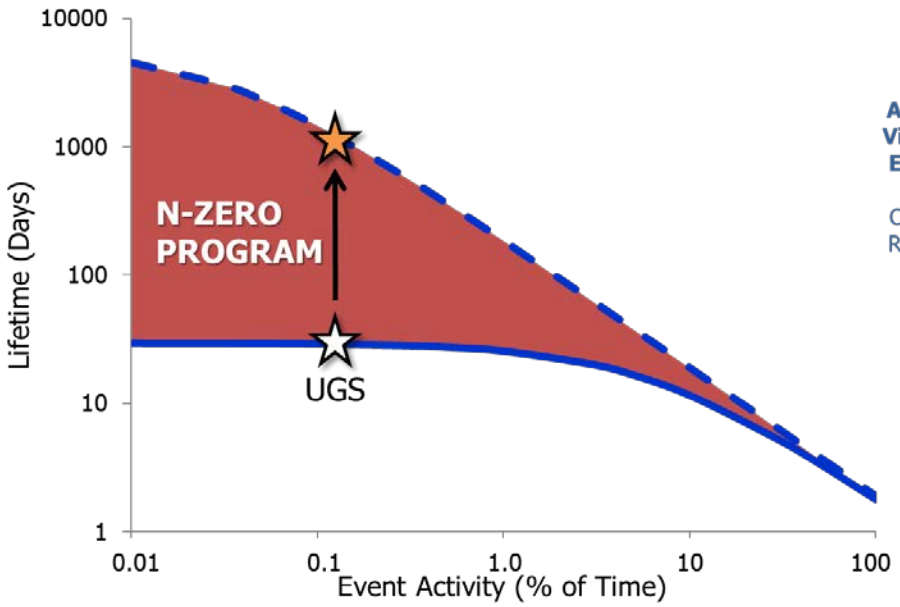
TA-2 Devices

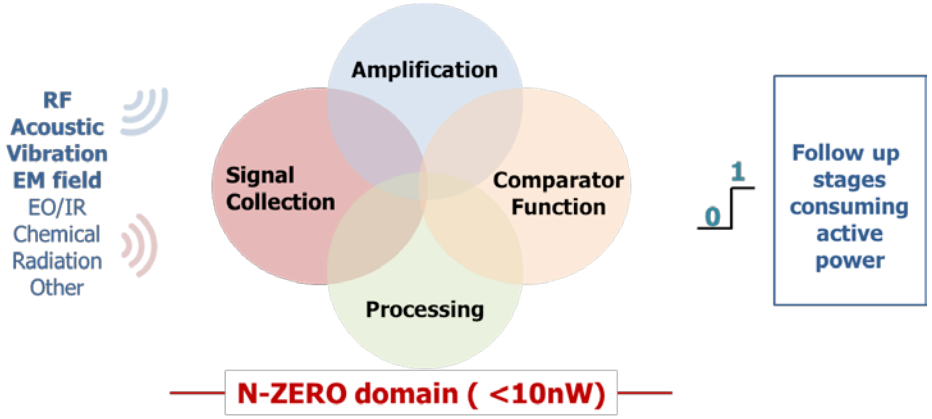


Dates

Abstracts due	February 20
Proposals due	April 23
Estimated Period of Performance Start	September 1

Summary





Continuous sensing only.

NO energy harvesting outside of the signature or alternate power sources.

	TA-1	TA-2
Focus	Microsystems	Devices
Funding	$25M	$5M
Phase I	15 mo.	15 mo.
Phase II	12 mo.	12-18 mo.
Phase III	12 mo.	N/A
Power Consumption	≤ 10 nW	≤ 10 nW

Abstracts due	February 20
Proposals due	April 23
Estimated Period of Performance Start	September 1

DARPA-BAA-15-14@darpa.mil

N-ZERO Question and Answer Session

A Notional Approach: Passive Sensing (Slide 13) Credits

- Tunnel FET – Alan C. Seabaugh, University of Notre Dame
- MEMS Switch – Jeff Pulskamp, ARL
- Acceleration Switch – Currano, et al., ARL
- Dispersive Delay Line – Vlasov et al., IBM
- Piezoelectric Transformer – Sarah Bedair et al., ARL and U. of FL
- GHz Acoustic Focusing – Sandia